

AD 714008

FINAL REPORT

Contract Number N00014-69-A-0200-8004

ARPA Order No. 125

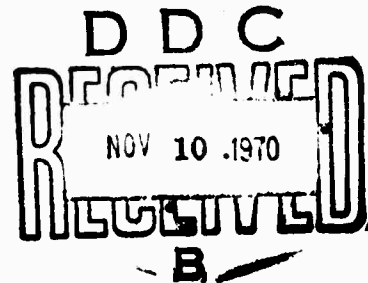
QUANTITATIVE STUDIES BY OPTICAL SPECTROSCOPY OF
ENERGY EXCHANGE MECHANISMS IN SIMPLE GASES AND SOLIDS

H. P. Broida
Contractor

University of California

Santa Barbara

Physics Department



Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
Springfield, Va. 22151

Distribution of this document is unlimited.

This document has been approved
for public release and sale for
distribution is unlimited

TABLE OF CONTENTS

Final Report
Quantitative Studies by Optical Spectroscopy of
Energy Exchange Mechanisms in Simple Gases and Solids

	<u>Page</u>
REPORT SUMMARY	1
ARTICLES PUBLISHED OR SUBMITTED	3
Ph.D. DEGREES	7
PUBLIC LECTURES OR FORUMS	8
SEMINARS IN MOLECULAR PHYSICS, UCSB	13
TECHNICAL REPORTS	15

REPORT SUMMARY

The ARPA/ONR supported research activity at the University of California, Santa Barbara, provided the major initial funding and a considerable fraction of later funding used in the establishment of a Molecular Physics Laboratory and in carrying out a considerable number of basic experimental studies. This laboratory emphasizes the use of optical spectroscopy and the teaching of skills for a thorough understanding and application of the observed spectra. The laboratory is now housed in rooms designed especially for optical spectroscopy, and equipment has been constructed on a modular basis providing for easy interchange of light sources, sample systems, spectroscopic detection apparatus, amplifiers and power supplies. A diverse assortment of spectroscopic equipment is available for the spectral range from 100 nm to 2000 nm with apertures as great as $f/0.87$ and resolving powers as high as 200,000. A "house" vacuum system provides extremely high speed pumping to moderate pressures (10^{-4} torr) and portable diffusion pumping apparatus provides pressures as low as 10^{-8} torr. A variety of white light and discrete light sources are available and state-of-the-art photon detectors can be used as needed for the desired spectral region. Several portable, low temperature cryostats have been constructed for optical studies on gases, liquids, solids and matrix isolated species. In recent years, several lasers have been added and the spectrometers are being used in conjunction with computers.

The laboratories are now used, in part, by three professors, four to 10 undergraduate students, four to six postdoctoral students and visiting senior faculty, three to five graduate students working for the Ph.D.

degree in physics and one to three other graduate students obtaining experience in spectroscopic laboratory research. For three years, the ARPA/ONR project was the only non-University support for Professor Broida and in the last four years has been a decreasing fraction of his support. Additionally in the last four years, an increasing fraction of the ARPA/ONR support was devoted to support of Professors Phillips, Walker, Glosser and Margolis. The project was a major source of funding outside of University sources for Professor Phillips.

A large fraction of the research concerned the measurement of molecular energy exchange in gases with an emphasis on electronically excited states.^{1,10,18,19,22,25,26,27,29,32,37,38,39,43,44,46,48,50*} Various sources were used to obtain easily interpretable conditions for collisional exchange of energy including flowing helium afterglows,^{10,43,44,46,50} flowing chemical afterglows,^{16,17,19,22,29,32,34,37,39} flames and explosions,^{1,31,36,38} and molecular beams.^{26,48} Liquids,^{2,3,6,30,47} solids,^{4,11,12,13,28,45,50,51} and matrix isolated molecules^{12a,13a,14,15,20,23,24,33,42,49} were studied from low to high temperatures in the attempt to learn more about molecular interactions. Investigations of laser systems^{7,8,9,18,19,25} and their application to molecular spectroscopy^{35,39,40,41,44a,47} have resulted in the development of several new and fruitful techniques.^{30,39,40,47} In addition to these more basic studies, some useful instruments and new techniques were developed and reported.^{2,5,7,21,31}

*Numbers refer to publications listed in the following two sections.

Articles published or submitted

<u>Author</u>	<u>Title</u>	<u>Journal</u>
1. Tj. Hollander	Photometric Measurements on the Deviations from the Equilibrium in Flames	A.I.A.A. January 1968 Paper 67-9
2. H. D. Pruett	Purification of Krypton by Directional Freezing	J. Phys. Chem. Solids <u>28</u> , 2346 (1968)
3. H. W. Offen D. T. Phillips	Fluorescence Lifetimes of Aromatic Hydrocarbons Under Pressure	J. Chem. Phys. <u>49</u> , 3995-7 (1968)
4. A. Matsui W. C. Walker	Exciton and Interband Spectra of Crystalline MnF_2	J.O.S.A. <u>60</u> , 358-65 (1970)
5. A. Matsui W. C. Walker	Polarization of Three Vacuum Ultraviolet Monochromators Measured with a Biotite Polarizer	J.O.S.A. <u>60</u> , 64-5 (1970)
6. C. M. Surka G. T. Beck F. Reif W. C. Walker	Spectroscopic Study of Liquid Helium in Ultraviolet	Phys. Rev. Letters <u>23</u> , 842-6 (1970)
7. D. T. Phillips J. West	The Poor Man's Nitrogen Laser	Am. J. Phys. <u>38</u> , 655-7 (1970)
8. G. Capelle D. T. Phillips	Pumping Organic Dyes with a Nitrogen Laser	Appl. Opt. <u>9</u> , 517 (1970)
9. G. Capelle D. T. Phillips	The Tuned Nitrogen Laser Pumped Dye Laser	Appl. Opt. Accepted
10. M. Manalis	Model for the Helium Afterglow	J. Chem. Phys. Submitted
11. P. A. Narayana P. Venkateswarlu	Electronic Absorption Spectrum of Ni^{2+} Doped in NH_4Cl Single Crystal	J. Chem. Phys. <u>52</u> , 5159-63 (1970)
12. K. V. S. Rao M. Dattatreya Sastry P. Venkateswarlu	Electron Paramagnetic Resonance Studies of VO^{2+} in Nitrate Single Crystals. II NH_4NO_3 , NaNO_3 , and $\text{Ba}(\text{NO}_3)_2$	J. Chem. Phys. <u>52</u> , 4035-40 (1970)
13. P. A. Narayana P. Venkateswarlu	Optical Absorption of Co^{2+} in Zinc Acetate Dihydrate Single Crystal	J. Chem. Phys. <u>53</u> , 281-4 (1970)

Articles published or submitted

<u>Co-Author with H. P. Broida</u>	<u>Title</u>	<u>Journal</u>
12a. S. Abramowitz	Vibration of Methane in Condensed Oxygen, Nitrogen, and Argon	J. Chem. Phys. <u>39</u> , 2383-4 (1964)
13a. A. M. Bass	Vacuum Ultraviolet Absorption Spectra of Oxygen in Liquid and Crystalline Argon and Nitrogen	J. Mol. Spectry. <u>12</u> , 221-30 (1964)
14. S. Abramowitz	The O-2 Transition of CO in Condensed Oxygen, Nitrogen and Argon	J. Research, NBS <u>68</u> , 331-3 (1964)
15. E. E. Ferguson	Charge-Transfer Absorption Spectra of NO in Kr and CH ₃ OH Solutions	J. Chem. Phys. <u>40</u> , 3715-6 (1964)
16. R. L. Brown	Spectral Study of Active Nitrogen Flames Exhibiting CN "Tail" Bands	J. Chem. Phys. <u>41</u> , 2053-60 (1964)
17. K. M. Evenson	Optical Detection of Microwave Transitions Between Excited Electronic States of CN Involved	Phys. Rev. <u>136</u> , 1566-71 (1964)
18. T. T. Kikuchi	Laser Possibilities of Chemically-Excited Molecules Formed with Atomic Species	Appl. Opt. Suppl. <u>2</u> , 171-8 (1965)
19.	Inverted Population Distributions Produced by Chemical Reactions	Appl. Opt. Suppl. <u>2</u> , 105-8 (1965)
20. E. E. Ferguson	A Possible Mechanism for Light Absorption by Interstellar Grains	Astrophys. J. <u>141</u> , 807-9 (1965)
21. F. C. Fehsenfeld K. M. Evenson	Microwave Discharge Cavities Operating at 2450 MHz	Rev. Sci. Instr. <u>36</u> , 294-8 (1965)
22. K. Schofield	Chemiluminescent Emission from the Reactions of Volatile Silicon Compounds and Active Nitrogen	Photochem. & Photobio. <u>9</u> , 989-1002 (1965)
23. R. L. Barger	Spectra of C ₃ in Solidified Gases at 4°K and 20°K	J. Chem. Phys. <u>43</u> , 2364-70 (1965)
24. R. L. Barger	Spectra of C ₂ in Solidified Gases at 4°K and 20°K	J. Chem. Phys. <u>43</u> , 2371-6 (1965)
25. K. M. Evenson T. T. Kikuchi	Comments on the Mechanism of the 337u CN Laser	J. Appl. Phys. <u>36</u> , 3355. (1965)
26. N. G. Utterback	Charge Transfer Excitation of CO ⁺ Comet-Tail Bands by Slow N ₂ ⁺ Ions	Phys. Rev. Letters <u>15</u> , 608-9 (1965)

<u>Co-Author with H. P. Broida</u>	<u>Title</u>	<u>Journal</u>
27. K. M. Evenson	Measurements of Collisional Energy Transfer Between Rotational Energy Levels in CN	J. Chem. Phys. <u>44</u> , 1637-41 (1966)
28. H. D. Pruett	Supercooling and Vapor Snake Formation in Xenon	J. Phys. Chem. Solids <u>27</u> , 1365-6 (1966)
29. M. I. Savadatti	Spectral Study of Flames of Carbon Vapor at Low Pressure	J. Chem. Phys. <u>45</u> , 2390-6 (1966)
30. S. L. Shapiro	Light Scattering from Fluctuations in Orientations of CS ₂ in Liquids	Phys. Rev. <u>154</u> , 129-38 (1966)
31. Tj. Hollander	Zeeman Scanning of Absorption Line Profiles in Flames	J. Quant. Spectry. Radiat. Transfer <u>7</u> , 965-8 (1967)
32. T. Iwai M. I. Savadatti	Mechanisms of Populating Electronically Excited CN in Active Nitrogen Flames	J. Chem. Phys. <u>47</u> , 3861-74 (1967)
33. H. D. Pruett	Free-Carrier Drift Velocity Studies in Rare-Gas Liquids and Solids	Phys. Rev. <u>164</u> , 1138-44 (1967)
34. T. Iwai	Optical Absorption Measurements of Ground State CN in Active Nitrogen Flames	J. Chem. Phys. <u>49</u> , 919-26 (1968)
35. K. Sakurai	Observation and Identification of I ₂ Fluorescence Excited by a 5682 Å Krypton Ion Laser	J. Chem. Phys. <u>50</u> , 557-8 (1969)
36. K. Schofield	Flame-Kinetic Studies - Methods of Experimental Physics, Vol. 7	Academic Press N.Y., 189-230 (1969)
37. R. J. Oldman	A Spectroscopic Study of Emission from Reactions of Barium in Flowing Afterglows	J. Chem. Phys. <u>51</u> , 2764-5 (1969)
38. R. J. Oldman	Time Resolved Spectroscopy in Acetylene/Oxygen Explosions	Combustion & Flame <u>14</u> , 61-6 (1970)
39. K. Sakurai S. E. Johnson	Laser-Induced Fluorescence of BaO	J. Chem. Phys. <u>52</u> , 1625-32 (1970)
40. K. Sakurai	Iodine Fluorescence Excited by the He-Ne 6328 Å Laser	J. Chem. Phys. <u>53</u> , 1615-6 (1970)
41. K. Sakurai	Measurements of Lifetimes and Quenching Cross Sections of the B $3\pi_{ou}^+$ State of Iodine using a Tunable Dye Laser	J. Chem. Phys. Accepted

<u>Co-Author with H. P. Broida</u>	<u>Title</u>	<u>Journal</u>
42. D. M. Mann	Ultraviolet Absorption Spectra of Transition Metal Atoms in Rare-Gas Matrices	J. Chem. Phys. Accepted
43. M. S. Manalis	Excitation of Neutral Atomic Nitrogen in a Helium Afterglow	In Preparation
44. M. S. Manalis	Vibrational Distributions of the N ₂ First Positive System Produced in a Flowing Helium Afterglow	In Preparation
44a. S. E. Johnson K. Sakurai	Fluorescence of Na ₂ Induced by a Helium-Neon Laser at 632.8 and 640.1 nm	J. Chem. Phys. <u>52</u> , 6441-2 (1970)

Ph.D. Degrees

45. Harold D. Pruett Free-Carrier Mobility Studies in the Rare-Gas Solids
August 1965
46. Jerry L. Dunn Spectral Analysis of Mechanisms and Kinetics of
Thermal Energy Reactions of Long-Lived Energetic
Helium Species with Simple Molecules
November 1966
47. Stanley L. Shapiro Light Scattering by Liquids and Molecular Solids
January 1967
48. Chelcie B. Liu Optical Spectra Observed During Ion-Molecule Collisions
with Low-Energy N_2^+ and Ar^+ Beams
September 1969
49. David M. Mann Ultraviolet Absorption Spectra of Transition Metal
Atoms in Rare-Gas Matrices
June 1970
50. Melvyn S. Manalis An Optical Spectroscopic Investigation of Helium
and Nitrogen Plasmas
July 1970
51. Jong-Jean Kim Raman Scattering from Ferroelectric Crystals of
KDP Family
July 1970

Public lectures or forums

<u>Date</u>	<u>Title</u>
12-63	Atlantic Research Corporation, Alexandria, Virginia "Chemical Reactions Leading to Population Inversions" (H. P. Broida)
12-63	American Physical Society Meeting, Pasadena, California "Absorption Spectrum and Intensity Effects of Barium in Solid Argon at 4°K" (H. P. Broida)
12-63	American Physical Society Meeting, Pasadena, California "Optical Detection of Microwave Transitions and Line Width Measurements in Electronically Excited CN" (H. P. Broida)
1-64	University of California, Berkeley, Physical Chemistry "Chemical Reactions Leading to Population Inversions" (H. P. Broida)
1-64	University of California, Berkeley, Solid State Physics "Spectra of Impurities in van der Waals' Solids" (H. P. Broida)
1-64	California Catalysis Meeting, Santa Barbara "A Physicist Tries to do Chemistry" (H. P. Broida)
4-64	University of Nevada, Reno, Nevada, Department of Physics "Optical Detection of Microwave Transitions in Electronically Excited CN" (H. P. Broida)
4-64	Dunn School, Los Olivos, California - Visiting Scientists Program in Physics "Frozen Free Radicals" (H. P. Broida)
4-64	National Bureau of Standards, Washington, D.C. "Optical Detection of Microwave Transitions in Electronically Excited CN and the Identification of the Transitions Involved" (K. Evenson)
8-64	Tenth Symposium (International) on Combustion, Cambridge, England "Some Observations on the Ionization of Alkali and Alkaline-Earth Elements in Hydrogen Flames" (K. Schofield)
9-64	Chemical Laser Conference, La Jolla, California "Inverted Population Distributions Produced by Chemical Reactions" (H. P. Broida)
9-64	Chemical Laser Conference, La Jolla, California "Laser Possibilities of Chemically-Excited Molecules" (T. Kikuchi)
10-64	University of California, Berkeley, Department of Physics "Dissociation Energy of the Alkaline Earth Oxides" (K. Schofield)

<u>Date</u>	<u>Title</u>
12-64	IDA Atomic and Molecular Advisory Panel (IDA-AMAP) Washington, D.C. (H. P. Broida)
1-65	University of California, Berkeley "Discharges in Iodine Vapor" (G. Woolsey)
2-65	University of Washington, Department of Physics, Seattle, Washington "Chemical Lasers" (H. P. Broida)
2-65	Chairman of first session Western Spectroscopy Association 12th Annual Meeting Asilomar, California "Spectroscopy with Lasers" (H. P. Broida)
3-65	San Diego State, Department of Physics, Journal Club "Free Carrier Mobility in Solid Argon" (H. Pruett)
3-65	Symposium on Chemiluminescence, U.S. Army Research Office, Durham, North Carolina "Chemiluminescent Emission from the Reactions of Volatile Silicon Compounds and Active Nitrogen" (K. Schofield)
4-65	Harvey Mudd College "Free Carrier Mobility in Solid Argon" (H. Pruett)
4-65	19th AMRAC Meeting (ARPA), Arlington, Virginia Discuss - Comments "Optical Observability of Ablative Re-entry Vehicles" (H. P. Broida)
5-65	Vandenberg Air Force Base "Chemical Lasers" - a presentation of basic laser principles and their relation to current work at UCSB (H. P. Broida)
5-65	IDA Panel on Optical Discrimination, Arlington, Virginia "Characteristic Distributions in Atomic and Molecular Radiation" (H. P. Broida)
5-65	Colorado State University, Graduate Colloquium "Free Carrier Mobility in Solid Argon" (H. Pruett)
6-65	Defense Atomic Support Agency at General Atomic, San Diego "Symposium on the Physics and Chemistry of the Earth's Atmosphere below 100 km" (H. P. Broida)
8-65	Radio Standards Laboratory Colloquium, NBS, Boulder "Free Carrier Mobility Studies in the Rare Gas Solids" (H. Pruett)
9-65	American Physical Society, Honolulu "Absorption Spectra of Solid Benzene Iodine" (J. Margolis)
9-65	American Physical Society, Honolulu "Free Carrier Mobility in Rare Gas Solids" (H. Pruett)

<u>Date</u>	<u>Title</u>
10-65	Chevron Research Company, Richmond, California a. "Chemical Lasers" (H. P. Broida) and b. "Double-resonance: Optical Detection of Microwave Transitions Between Electronically Excited States of CN" (H. P. Broida)
11-65	UCSB Physics Colloquium "Microwave Optical Techniques for Measuring Collisional Energy Transfer" (H. P. Broida)
12-65	American Physical Society, Los Angeles a. "Reactions of Carbon Vapour" (M. I. Savadatti) b. "Brillouin-Scattering Determination of the Dispersion of Hypersound in Liquid NH_3 , H_2O , and C_6H_6 " (S. L. Shapiro) c. "Brillouin Scattering at 4880 \AA " (S. L. Shapiro)
12-65	American Association for the Advancement of Science Symposium, Berkeley "Vibration and Rotation Energy Transfer Processes Detected by the Emission of Photons" (H. P. Broida)
3-66	Lockheed Missiles and Space Company, Palo Alto "Microwave-Optical Technique for Measuring Collisional Energy Transfer of Molecules" (H. P. Broida)
5-66	Battelle Memorial Institute, Columbus, Ohio "Double-Resonance Experiments in CN" (H. P. Broida)
5-66	UCLA, Department of Chemistry Seminar "Rotational and Vibrational Relaxation" (H. P. Broida)
5-66	University of Southern California, Los Angeles, Dept. of Chemistry "Microwave-Optical Technique for Measuring Collisional Energy Transfer" (H. P. Broida)
5-66	UCLA, Physics Colloquium "Microwave-Optical Technique for Measuring Collisional Energy Transfer for Molecules" (H. P. Broida)
8-66	JILA Colloquium "Microwave-Optical Technique for Measuring Collisional Transfer of Rotational Energy" (H. P. Broida)
9-66	Molecular Spectroscopy Symposium in Columbus, Ohio "Light Scattering from Fluctuations in Orientations of CS_2 in Liquids" (S. L. Shapiro)
10-66	Optical Society of America, San Francisco, California "Intensity Correlation Measurements" (D. T. Phillips)

<u>Date</u>	<u>Title</u>
10-66	Optical Society of American, San Francisco, California "Intensity Correlations in Multimode Laser" (D. T. Phillips)
12-66	Institute for Defense Analyses, Arlington, Virginia "Present Knowledge of Spectroscopic Population Measurements" (H. P. Broida)
1-66	American Physical Society meeting, Stanford "Raman Scattering in Liquid and Solid Carbon Monoxide and Nitrogen" (S. L. Shapiro)
1-67	A.I.A.A. Fifth Aerospace Sciences Meeting, New York "Photometric Measurements on the Deviations from the Equilibrium in Burnt Gases" (Tj. Hollander)
2-67	Panelist - National Science Foundation Instructional Scientific Equipment Program, San Francisco, California (H. P. Broida)
3-67	Air Force Cambridge Research Laboratories, Bedford, Massachusetts "Gases and Discharge Phenomena" (H. P. Broida)
3-67	Lincoln Laboratory (MIT), Lexington, Massachusetts "Spectroscopic Population Measurements" (H. P. Broida)
6-67	Jet Propulsion Laboratory, Pasadena, California "Double Resonance of Electronically Excited CN" (H. P. Broida)
8-67	Co-host Photophysics and Photochemistry discussion for ONR, Santa Barbara, California (H. P. Broida)
7-67	Fifth International Conference on the Physics of Electronic and Atomic Collisions, Leningrad, USSR "Measured Room Temperature Reaction Rates of Metastable and Ionic Helium with Several Molecules" (H. P. Broida)
7-67	Institute of Chemical Physics, Moscow, USSR "Reactions of Energetic Helium" (H. P. Broida)
7-67	Institute of Chemical Physics, Moscow, USSR "Double Resonance Studies of Electronically Excited CN" (H. P. Broida)
9-67	International Congress on Magnetism, Cambridge, Massachusetts "Nuclear Relaxation Rates in Single-Domain Cobalt" (W. Kaplan)
12-67	Rotary Club, Santa Barbara, California "Trip to Russia" (H. P. Broida)
12-67	American Physical Society meeting, Pasadena, California "A New Method for Excitation of Neutral Atomic Nitrogen" (M. Manalis)

<u>Date</u>	<u>Title</u>
6-68	Presides over - American Physical Society meeting Los Alamos, New Mexico Atomic and Molecular Collisions" Radiation Processes Section (H. P. Broida)
8-68	Co-hosts Photophysics and Photochemistry discussion for ONR, Santa Barbara, California (H. P. Broida and D. T. Phillips)
12-68	American Physical Society meeting, San Diego, California "Vibrational Distributions of the $H_2(B\ 3\pi_g - A\ 3\sigma_u^+)$ System Produced in a Helium Afterglow (M. Manalis)
4-69	Seminar - Chemistry Department, University of Washington "Lasers as a Tool for Studies of Energy Transfer Processes in Small Molecules (H. P. Broida)
4-69	Seminar - Chemistry Department, University of Washington "Low Temperature Spectroscopy" (H. P. Broida)
4-69	Seminar - Chemistry Department, University of Washington "Trapped Radicals" (H. P. Broida)
8-69	Ninth Free Radical Symposium, Banff, Canada "The Interpretation of the Ultraviolet Spectra of Mers from Mariner 6" (H. P. Broida)
8-69	Chairman, Ninth International Symposium on Free Radicals, Banff Canada (H. P. Broida)
8-69	Chairman, Optical Spectroscopy of Free Radicals in the Gas Phase Session of the Ninth International Symposium on Free Radicals, Banff, Canada (H. P. Broida)
2-70	Graduate Student Seminar, Department of Physics, UCSB "Optical Spectroscopy" (H. P. Broida)
4-70	National Research Council of Canada, Banff, Canada "Laser Fluorescence Spectroscopy" (H. P. Broida)

Seminars in Molecular Physics, UCSB

<u>Date</u>	<u>Title</u>
10-64	"Rayleigh, Raman, and Brillouin Scattering in Molecular Solids" (S. Shapiro)
10-64	"Electronegative Plasmas in the Iodine Gas Discharge" (G. Woolsey)
11-64	"Use of Green's Function in Spectroscopy" (J. Margolis)
3-65	"Experimental Investigations of Free Carrier Mobility in Solid Argon" (H. Pruett)
3-65	"Chemiluminescent Emission from the Reactions of Volatile Silicon Compounds and Active Nitrogen" (K. Schofield)
4-65	"Molecular Spectra and Chemical Lasers" (C. Liu)
4-65	"The Brush Cathode Plasma" (G. Woolsey)
5-65	"Scattering of Laser Light by Sound Waves" (S. Shapiro)
10-65	"Photoionization of Aromatic Molecules in Rigid Glasses" (M. I. Savadatti)
10-65	"Brillouin Scattering" (S. L. Shapiro)
11-65	"Spectroscopic Determination of Charge Exchange Cross Sections" (C. Liu)
2-66	"Molecular Spectroscopy" (H. P. Broida)
2-66	"Molecular Spectroscopy. Measurement of Thermal Energy Reaction Rates" (J. L. Dunn)
3-66	"Spectroscopic Study of Reactions of Carbon Vapor" (M. I. Savadatti)
3-66	"Spectroscopic Study of Molecular Collisions" (C. Liu)
5-66	"Light Scattering in Anisotropically Polarizable Liquids" (S. L. Shapiro)
10-66	"Light Scattering by Liquids" (S. Shapiro)
11-66	"The Schrodinger Equation without Quantum Mechanics" (D. T. Phillips)
1-67	"Intensity Correlation Spectroscopy I 'Classical Theory'" (D. T. Phillips)
1-67	"Nuclear Relaxation in Magnetic Materials" (H. Kaplan)
2-67	"Photometric Observations of Deviations from Equilibrium in Flames" (Tj. Hollander)

<u>Date</u>	<u>Title</u>
4-67	"Polarization Correlation" (D. T. Phillips)
4-68	"Relativistic Radiation Theory" (D. T. Phillips)
4-68	"Non-Relativistic Quantum Optics" (D. T. Phillips)
4-68	"Coherent States of the Radiation Field" (D. T. Phillips)
10-68	"Lasers as a Tool for Studies of Energy Transfer Processes in Small Molecules" (H. P. Broida)
2-69	"Atomic Nitrogen" (M. Manalis)

Technical Reports				Co-Author with	
Number	Title	Pages	Date	H. P. Broida	
TR 1	Quantitative Studies by Optical Spectroscopy of Energy Exchange Mechanisms in Simple Gases and Solids	35	7/64	Schofield, Milne Dunn, Shapiro Pruett	
TR 2	Quantitative Studies by Optical Spectroscopy of Energy Exchange Mechanisms in Simple Gases and Solids	30	1/65	Schofield, Dunn, Milne, Woolsey, Shapiro, Pruett, Margolis	
TR 3	Spectral Study of Active Nitrogen Flames Exhibiting CN "Tail" Bands	8	2/65	R. L. Brown	
TR 4	Charge-Transfer Absorption Spectra of NO in Kr and CH ₃ OH Solutions	2	3/65	E. E. Ferguson	
TR 5	Optical Detection of Microwave Transitions Between Excited Electronic States of CN and the Identification of the Transitions Involved	6	3/65	K. M. Evenson J. L. Dunn	
TR 6	Laser Possibilities of Chemically Excited Molecules Formed with Atomic Species	7	4/65	T. T. Kikuchi	
TR 7	Inverted Population Distributions Produced by Reactions	4	4/65		
TR 8	A Possible Mechanism for Light Absorption by Interstellar Grains	3	4/65	E. E. Ferguson	
TR 9	Microwave Discharge Cavities Operating at 240 MHz	2	5/65	F. C. Fehsenfeld K. M. Evenson	
TR 10	Vibraluminescence of CO ₂ and N ₂ O in Active Nitrogen	2	7/65	E. L. Milne M. Steinberg	
TR 11	Quantitative Studies by Optical Spectroscopy of Energy Exchange Mechanisms in Simple Gases and Solids	21	7/65	Pruett, Shapiro Margolis, Dunn Schofield, Woolsey	
TR 12	Free-Carrier Mobility Studies in the Rare-Gas Solids	125	1/66	H. D. Pruett	
TR 13	Charge-Transfer Excitation of CO ⁺ Comet-Tail Bands by Slow N ₂ ⁺ Ions	2	1/66	N. G. Utterback	
TR 14	Spectra of C ₃ in Solidified Gases at 4° and 20°K	7	12/65	R. L. Barger	
TR 15	Spectra of C ₂ in Solidified Gases at 4° and 20°K	6	12/65	R. L. Barger	
TR 16	Chemiluminescent Emission from the Reaction of Volatile Silicon Compounds and Active Nitrogen	14	3/66	K. Schofield	
TR 17	Comments on the Mechanism of the 337-Micron CN Laser	1	5/66	K. M. Evenson T. T. Kikuchi	
TR 18	Measurements of Collisional Energy Transfer	5	7/66	K. M. Evenson	
TR 19	Supercooling and Vapor Snake Formation in Xenon	2	8/66	H. D. Pruett	
TR 20	Spectral Analysis of Mechanisms and Kinetics of Thermal Energy Reactions of Long-Lived Energetic Helium Species with Simple Molecules	146	12/66	J. L. Dunn	
TR 21	Light Scattering by Liquids and Molecular Solids	118	1/67	S. L. Shapiro	
TR 22	Photometric Measurements on the Deviations from the Equilibrium State in Burnt Flame Gases	15	7/67	Tj. Hollander	
TR 23	Purification of Krypton by Directional Freezing	2	1/68	H. D. Pruett	
TR 24	Zeeman Scanning of Absorption Line Profiles in Flames	4	2/68	Tj. Hollander	
TR 25	Mechanisms of Populating Electronically Excited CN in Active Nitrogen Flames	14	3/68	T. Iwai, M. I. Savadatti	
TR 26	Free-Carrier Drift-Velocity Studies in Rare-Gas Liquids and Solids	5	3/68	H. D. Pruett	
TR 27	Photometric Measurements on the Deviations from the Equilibrium State in Flames	9	4/68	Tj. Hollander	
TR 28	Optical Absorption Measurements of Ground-State CN in Active Nitrogen Flames	8	12/68	T. Iwai D. W. Pratt	
TR 29	Optical Spectra Observed During Ion-Molecule Collisions with Low-Energy N ₂ ⁺ and Ar ⁺ Beams	215	11/69	C. B. Liu	

<u>Number</u>		<u>Title</u>	<u>Pages</u>	<u>Date</u>	Co-Author <u>H. P. Broida</u>
TR	30	Ultraviolet Absorption Spectra of Transition Metal Atoms in Rare-Gas Matrices	123	8/70	D. M. Mann
TR	31	An Optical Spectroscopic Investigation of Helium and Nitrogen Plasmas.	156	8/70	M. S. Manalis

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) University of California, Santa Barbara		2a. REPORT SECURITY CLASSIFICATION Unclassified	
		2b. GROUP	
3. REPORT TITLE FINAL REPORT QUANTITATIVE STUDIES BY OPTICAL SPECTROSCOPY OF ENERGY EXCHANGE MECHANISMS IN SIMPLE GASES AND SOLIDS			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) FINAL REPORT			
5. AUTHOR(S) (Last name, first name, initial) Broida, H. P.			
6. REPORT DATE August 31, 1970		7a. TOTAL NO. OF PAGES 15	7b. NO. OF REFS 54
8a. CONTRACT OR GRANT NO. N00014-69-A-0200-8004		8a. ORIGINATOR'S REPORT NUMBER(S) None	
b. PROJECT NO. ARPA Order No. 125		8b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) None	
c.			
d.			
10. AVAILABILITY/LIMITATION NOTICES Distribution of this document is unlimited			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY U.S. Advanced Research Projects Agency through the U.S. Office of Naval Research	
13. ABSTRACT None			

14.

KEY WORDS

Optical Spectroscopy
 Energy Exchange Mechanisms
 Simple Gases
 Simple Solids
 Electronically Excited States
 Molecular Spectroscopy
 Matrix isolated molecules
 Afterglows

LINK A

LINK B

LINK C

ROLE

WT

ROLE

WT

ROLE

WT

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parentheses immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those

imposed by security classification, using standard statements such as:

- (1) "Qualified requesters may obtain copies of this report from DDC."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."
- (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.